Stabilized Adaptive Optics Imaging for Laser Microsurgery

NIH NIBIB
Image Guided Interventions Workshop

D. X. Hammer
Physical Science Inc.
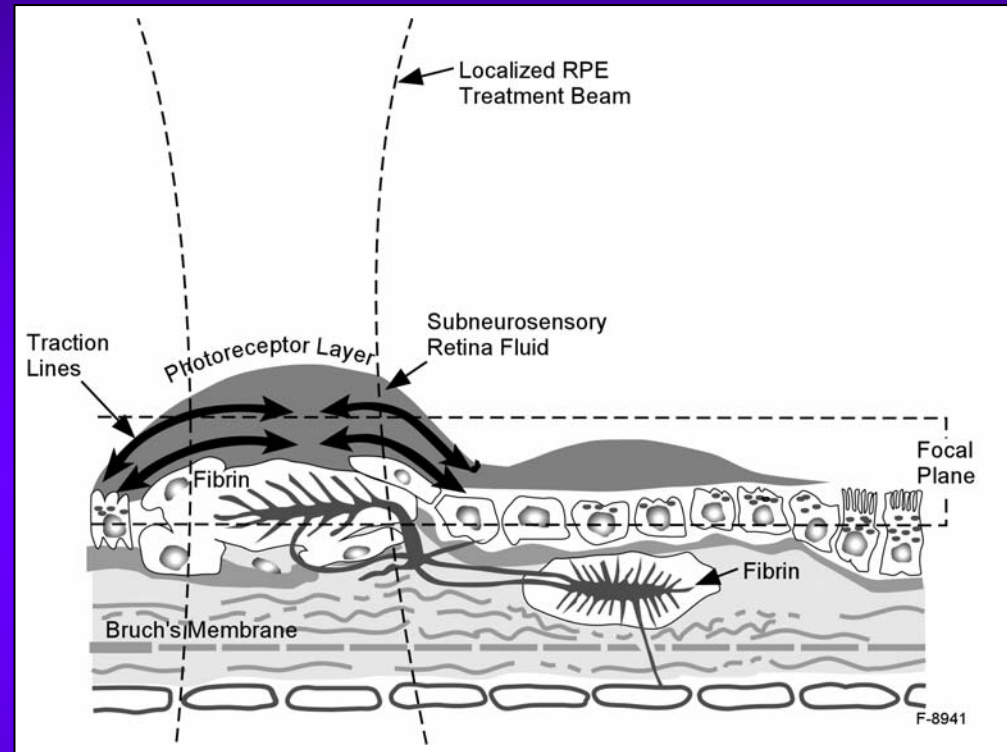*Andover MA*

Support by EB003111

13-14 May 2004

Program Objectives

- **Overall Program Goal**
  - Design, construct, and test a prototype clinical imaging and irradiation system, based upon adaptive optics, retinal tracking, and ultrashort laser pulse-induced retinal damage mechanisms.

- **Specific Program Objectives**
  - Design and construct an adaptive optics scanning laser ophthalmoscope (AOSLO).
  - Integrate a retinal tracker into the AOSLO (TAOSLO).
  - Characterize the TAOSLO imaging and tracking performance in human subject tests at PSI.
  - Deliver and setup the TAOSLO for ultrashort pulse delivery at the Optical Radiation Branch (AFRL/HEDO, Brooks AFB TX) and test in an animal model.
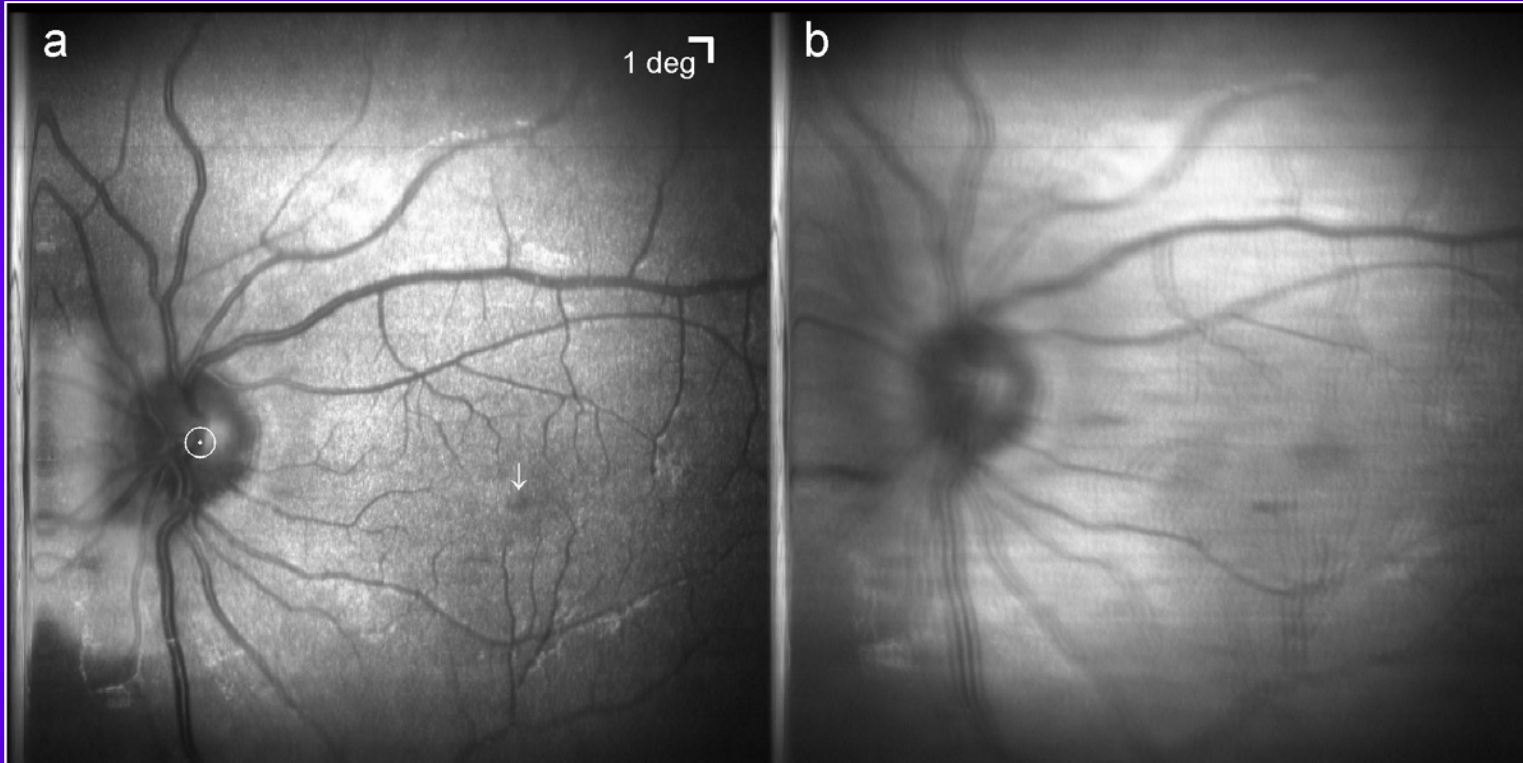
Motivation and Clinical Significance

- **Advances in diagnostic laser technologies have far outpaced advances in laser therapies (except for PDT)**
- **Retinal diseases**
  - **Age-related macular degeneration (AMD)**
  - **Diabetic retinopathy (DR)**
  - **Retinitus pigmentosa (RP)**
  - **Intraocular melanoma (IM)**
- **Potential therapies with the proposed system - Early detection and treatment for:**
  - **Selective destruction of RPE with ultrashort pulses (fs-ns)**
  - **Destruction of feeder vessels in choroidal neovascularization (CNV) related to DR**
  - **Other potential targets: drusen, small tumors, microaneurysms**

Labels in figure: Localized RPE Treatment Beam; Subneurosensory Retina Fluid; Photoreceptor Layer; Traction Lines; Focal Plane; Fibrin; Fibrin; Bruch's Membrane; F-8941

AMD retinal pathology
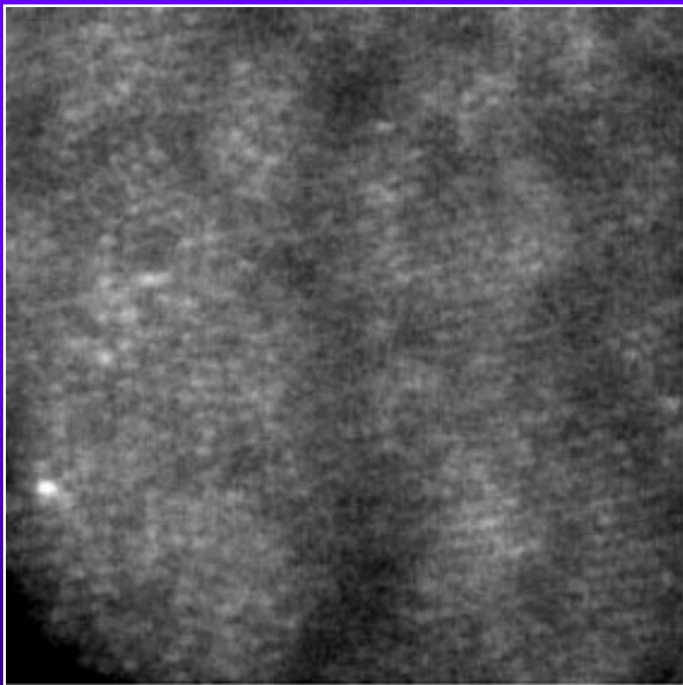
Core Technology
Retinal Tracking

- **PSI's retinal tracking technology**
  - US Patents 5,767,941 and 5,943,115
  - Enables visualization, photonic analysis, and phototherapy of retinal structures with superior sensitivity and resolution
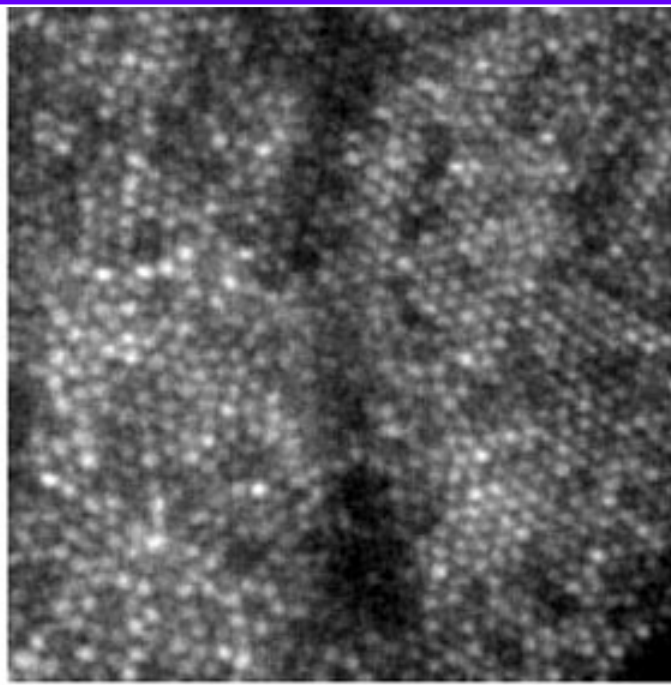 - Absolutely required for precision laser retinal surgery

PSI

Core Technology
Adaptive Optics

- **Correction of ocular aberrations by wavefront compensation & correction allows increased transverse resolution for several imaging technologies (e.g. SLO and OCT)**
- **For precision laser retinal surgery, AO is necessary to achieve a diffraction-limited spot at the retina**

Without Compensation   With Adaptive Compensation   5 arcmin

Cone mosaic imaged with and without wavefront compensation

Used with permission from Austin Roorda: http://www.opt.uh.edu /research/aroorda

Core Technology
Ultrashort Pulse Laser Damage

- **Non-linear mechanisms (primarily optical breakdown) mediate retinal damage from ultrashort pulses (< 10 ns).**
- **Ultrashort pulse damage is therefore characterized by**
  - **Low energy thresholds**
  - **Highly localized damage with little collateral damage**
- **Recent engineering advances are moving ultrashort pulse lasers closer to routine use in clinical systems (OCT, refractive surgery, etc.)**
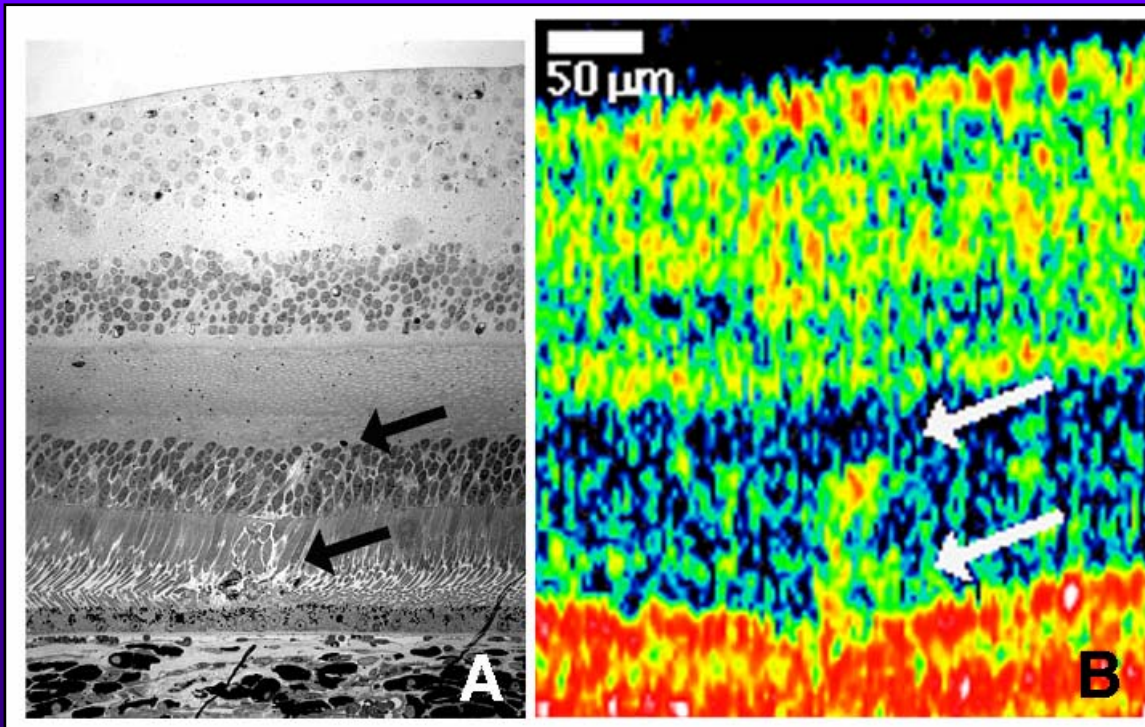
Histology and OCT image of RPE disruption from 3 ps pulses.

Roach et al. JBO, in press.

System Overview
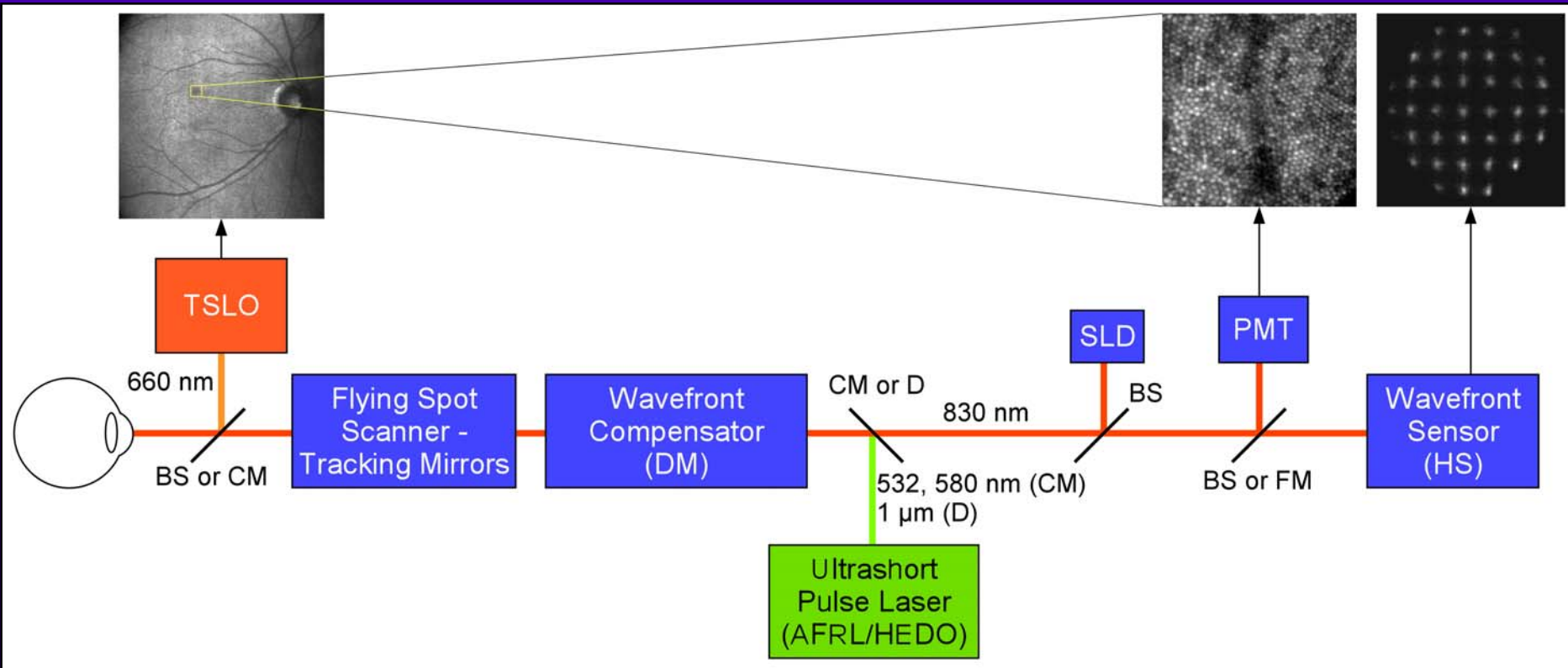
- **Dichroic beamsplitter (D)**
  - **400-860 nm   R > 95%**
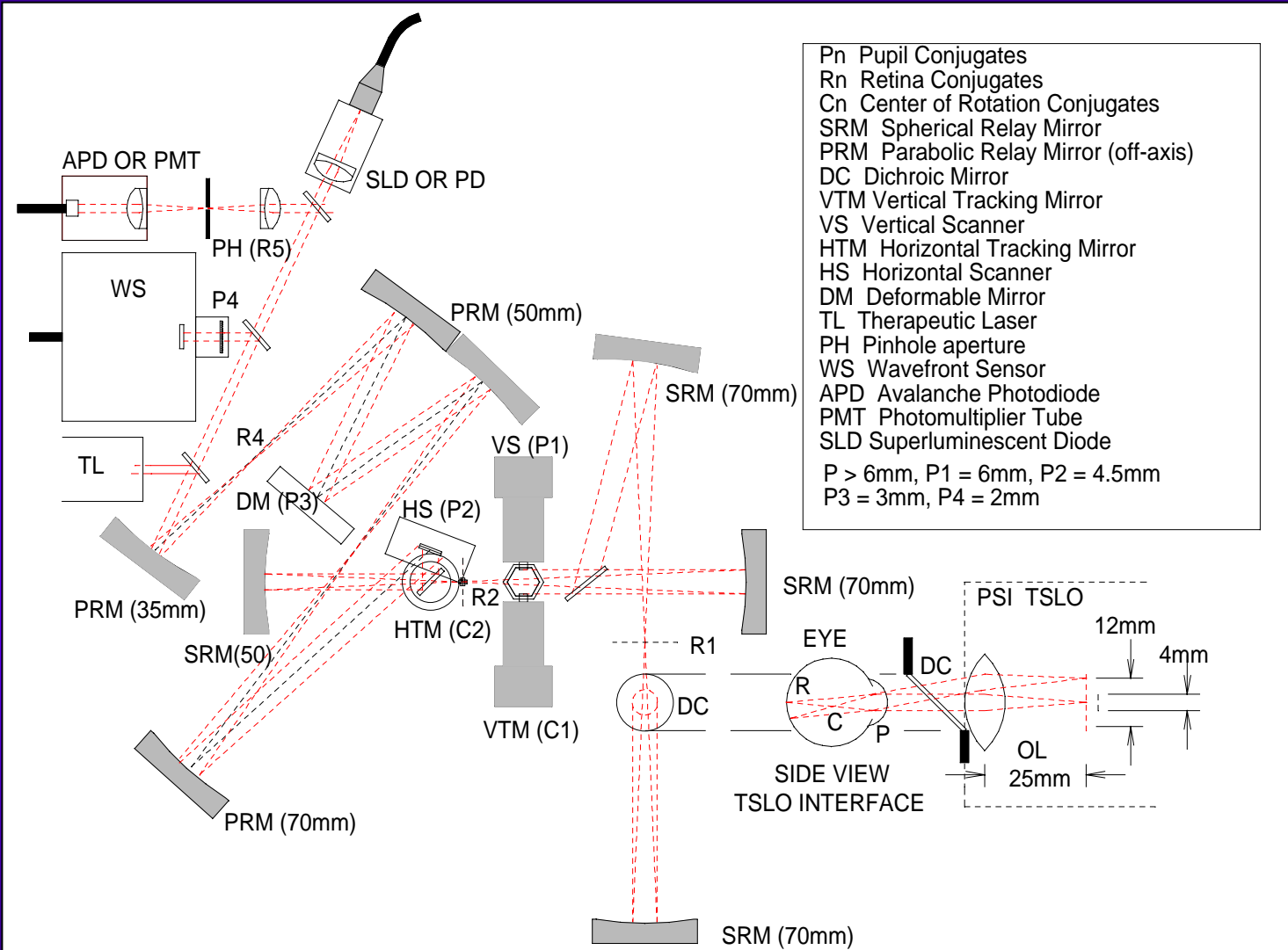 - **870-1100 nm T > 85%**
- **Cold mirror (CM)**
  - **400-700 nm   R > 95 %**
  - **780-1250 nm T > 85%**

TAOSLO Optical Schematic

APD OR PMT

SLD OR PD

PH (R5)

WS

P4

PRM (50mm)

SRM (70mm)

TL

R4

VS (P1)

DM (P3)

HS (P2)

PRM (35mm)

R2

SRM (70mm)

PSI TSLO

SRM(50)

HTM (C2)

R1

EYE

12mm

4mm

DC

R

DC

VTM (C1)

C

P

OL

PRM (70mm)

SIDE VIEW
TSLO INTERFACE

25mm

SRM (70mm)

Pn Pupil Conjugates
Rn Retina Conjugates
Cn Center of Rotation Conjugates
SRM Spherical Relay Mirror
PRM Parabolic Relay Mirror (off-axis)
DC Dichroic Mirror
VTM Vertical Tracking Mirror
VS Vertical Scanner
HTM Horizontal Tracking Mirror
HS Horizontal Scanner
DM Deformable Mirror
TL Therapeutic Laser
PH Pinhole aperture
WS Wavefront Sensor
APD Avalanche Photodiode
PMT Photomultiplier Tube
SLD Superluminescent Diode

P > 6mm, P1 = 6mm, P2 = 4.5mm
P3 = 3mm, P4 = 2mm

PHYSICAL SCIENCES INC.

TAOSLO Instrumentation

- **Custom PCB**
  - **LUT to linearize SLO image resonant scanner**
  - **Synchronize and drive vertical scanner**
- **3 framegrabbers (FG)**
  - **TSLO**
  - **Flying-spot SLO**
  - **WS**
- **RT controller**
  - **Retinal tracking bandwidth > 1 kHz**
  - **AO closed-loop bandwidth > 10 Hz**

Research Plan and Acknowledgments

- **Research Plan**
  - **Optical and instrumentation design complete**
  - **System construction complete by Fall**
  - **Human and animal subject testing in 2005**
- **Acknowledgments**
  - **Physical Sciences Inc.**
    - **R. Daniel Ferguson**
    - **Nick Iftimia**
  - **Brooks AFB**
    - **Benjamin A. Rockwell**
    - **Clarence Cain**
    - **David Stolarski**
  - **Consulting support**
    - **Austin Roorda, University of Houston School of Optometry**
    - **H. Grady Rylander III, University of Texas at Austin and Eye Institute of Austin**